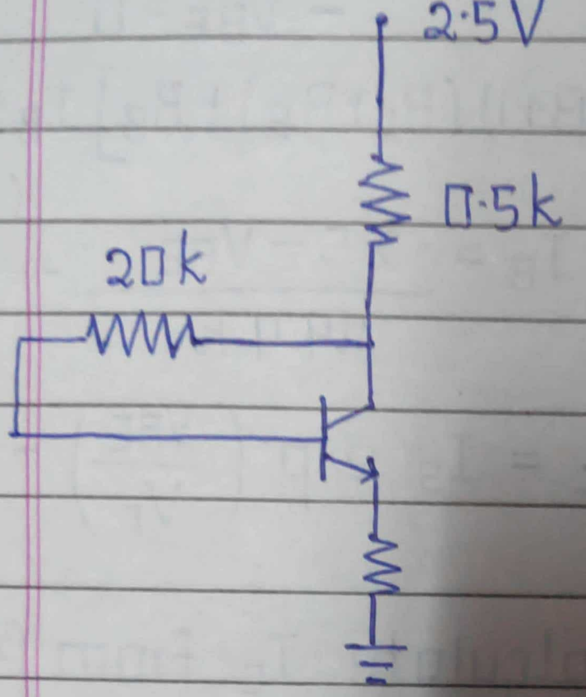
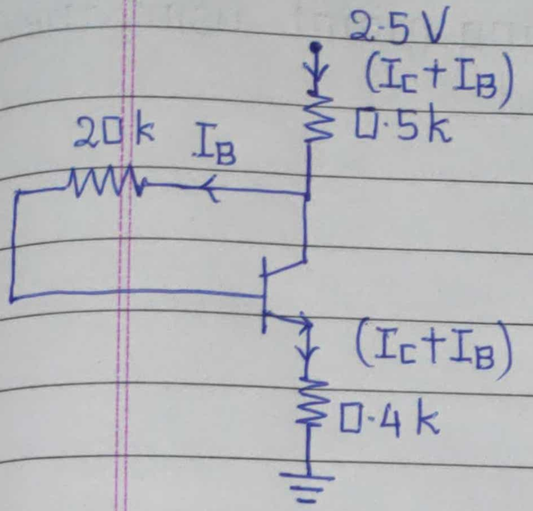
Q.1. Given $I_S = 6 \times 10^{-16}$ A, $\beta = 10$, $V_{th} = 0.026$ V calculate the DC operating point using the two approaches discussed.



Sol^n: Approach I:



Applying KVL,

$$V_{CC} - (I_C+I_B)(R_C+R_E) - I_B R_B - V_{BE} = 0$$

$$[(\beta+1)(R_C+R_E)+R_B]\, I_B = V_{CC} - V_{BE} \quad (\because I_C = \beta I_B)$$

$$\therefore I_B = \frac{2.5 - V_{BE}}{29.9\,k} \quad \text{—— ①}$$

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \quad \text{—— ②}$$

(1) Assume $V_{BE} = 0.7$ V, calculate I_C from ②

$$I_C = 295.59\ \mu A$$

(2) $\therefore I_B = \frac{I_C}{\beta} = 29.559\ \mu A$

(3) Recalculate V_{BE} from ①

$$V_{BE} = 1.616\ V$$

which diverges greatly from the assumed value

Approach 2:

By KVL, we get $I_B = \frac{2.5 - V_{BE}}{29.9k}$

$$I_C = \beta I_B = 10\ \frac{2.5 - V_{BE}}{29.9\,k} \quad \text{—— ③}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) = 0.026 \ln\left(\frac{I_C}{6\times10^{-16}}\right) \quad \text{—— ④}$$

Assume $V_{BE} = 0.7V$, calculate I_C

$$I_C = 602\ \mu A$$

Using eq^n ④, recalculate V_{BE} ($V_{BE} = 0.718$ V)

Again calculate I_C

$$I_C = 595.99\ \mu A.$$

Repeat the steps until convergence.

Finally,

$$V_{BE} = 0.718\ V,\ I_C = 595.99\ \mu A$$

Q.2 (i) Calculate the operating pt. (values of V_{BE} and I_C) for the two circuits given below.
Assume $\beta = 100$ and $I_S = 10^{-17}$ A. Also $V_{th} = 0.026$ V

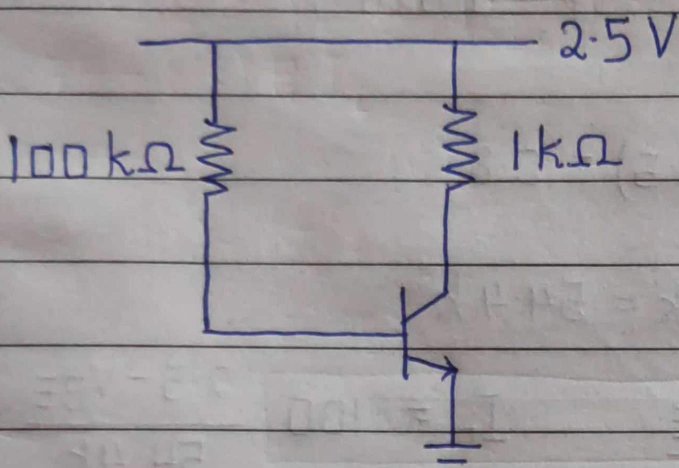


Fig (1): Simple Biasing

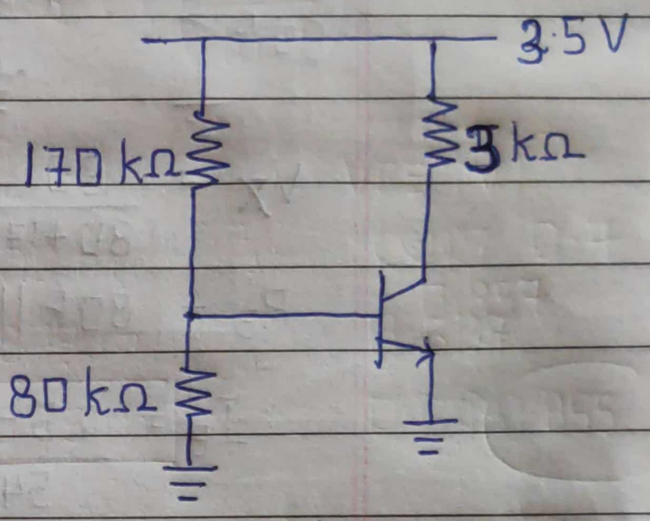
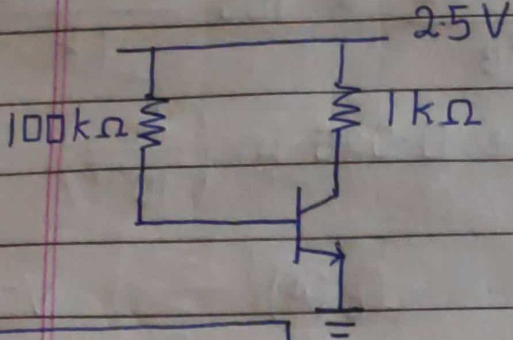


Fig. (2): Resistive Divider Biasing

(ii) Now, if the supply voltage decreases by 10%, find the operating point.

(iii) If the supply voltage increases by 10% from the original value, again calculate the operating point.

Sol^n: For simple biasing circuit,



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{2.5 - V_{BE}}{100k}$$

$$I_C = \beta I_B = 100 \, \frac{2.5 - V_{BE}}{100k} \quad \text{—— ①}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$$

$$V_{BE} = 0.026 \ln\left(\frac{I_C}{10^{-17}}\right) \quad \text{—— ②}$$

$$\boxed{\begin{aligned} V_{CE} &= V_{CC} - I_C R_C \\ &= 2.5 - (1k) I_C \end{aligned}}$$

(i) For $V_{CC} = 2.5$ V, assume $V_{BE} = 0.7$ V initially.

V_{BE} (V)	I_C (A)	V_{CE} (V)
0.7	1.8 m	0.7
0.853	1.647 m	0.853
$\boxed{0.851}$	$\boxed{1.649 m}$	0.851

(1) Assume $V_{BE} = 0.7$ V initially, calculate I_C from ①

$I_C = 1.8$ mA

(2) Now substituting $I_C = 1.8$ mA in ②, calculate V_{BE}.

(3) $V_{BE} = 0.853$ V

Repeat the steps until V_{BE} converges.

(ii) For $V_{CC} = 0.9 \times 2.5 = 2.25$ V,

$$I_C = \beta I_B = 100 \, \frac{2.25 - V_{BE}}{100k}$$

$$V_{CE} = 2.25 - (1k) I_C$$

$$V_{BE} = 0.026 \ln\left(\frac{I_C}{10^{-17}}\right)$$

V_{BE} (V)	I_C (A)	V_{CE} (V)
0.7	1.55 m	0.7
0.85	1.4 m	0.85
$\boxed{0.847}$	$\boxed{1.403 m}$	0.847

(iii) For $V_{CC} = 2.75\text{ V}$ $\quad (1.1 \times 2.5 = 2.75\text{ V})$

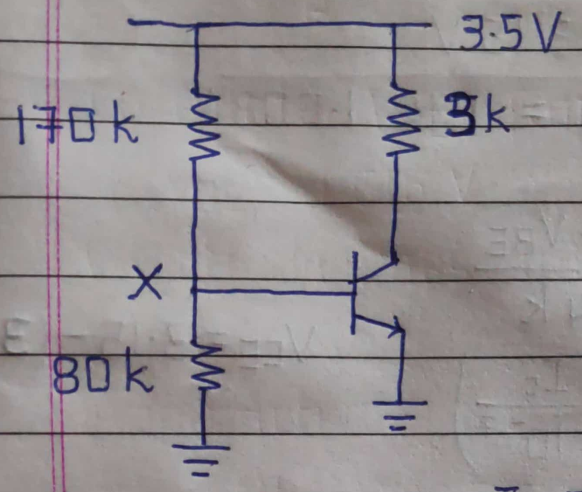
$$I_C = \beta I_B = \beta \frac{V_{CC} - V_{BE}}{R_B} = 100 \frac{2.75 - V_{BE}}{1k}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) = 0.026 \ln\left(\frac{I_C}{10^{-17}}\right)$$

$V_{CE} = 2.75 - (1k)\, I_C$

V_{BE} (V)	I_C (A)	V_{CE} (V)
0.7	2.05 m	~~0.45~~ 0.7
0.857	1.893 m	~~0.607~~ 0.857
$\boxed{0.855}$	$\boxed{1.895\text{ m}}$	~~0.605~~ 0.855

(i) For resistive divider biasing,

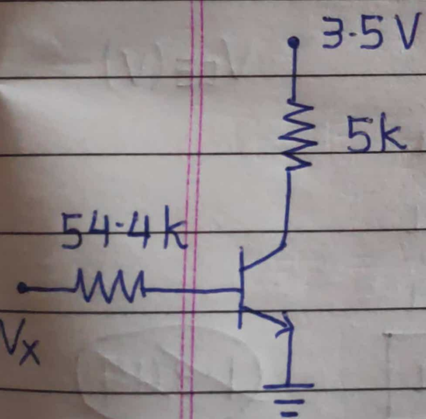


$$V_x = \frac{80}{80+170}(3.5) = 1.12\,V$$

$$R_{Thev} = 170k \,||\, 80k = 54.4\,k\Omega$$

$$I_B = \frac{V_x - V_{BE}}{R_{Thev}} = \frac{1.12 - V_{BE}}{54.4k}$$

$$I_C = \beta I_B = 100\,\frac{1.12 - V_{BE}}{54.4k} \quad \text{——} \; (3)$$



$$V_{BE} = 0.026 \ln\left(\frac{I_C}{I_S}\right)$$

$$= 0.026 \ln\left(\frac{I_C}{10^{-17}}\right) \quad \text{——} \; (4)$$

$$V_{CE} = V_{CC} - I_C R_C = 3.5 - (3k)\, I_C \quad \text{——} \; (5)$$

Follow the same procedure as for simple biasing.

(ii) For $V_{CC} = 0.9 \times 3.5 = 3.15\,V$

$$V_x = \frac{80}{80+170}(3.15) = 1.008\,V$$

$$\therefore I_E = 100\,\frac{1.008 - V_{BE}}{54.4k}$$

$$V_{CE} = 3.15 - (3k)\,I_E$$

$$V_{BE} = 0.026 \ln\left(\frac{I_C}{10^{-17}}\right)$$

V_{BE} (V)	I_E (A)	V_{CE} (V)
0.7	566.18 μ	
0.823	340.07 μ	
0.81	363.97 μ	
$\boxed{0.812}$	$\boxed{360.29\,\mu}$	~~1.349~~
		2.064

(iii) For $V_{CC} = 1.1 \times 3.5 = 3.85\,V$

$$V_x = \frac{80}{80+170}(3.85) = 1.232\,V$$

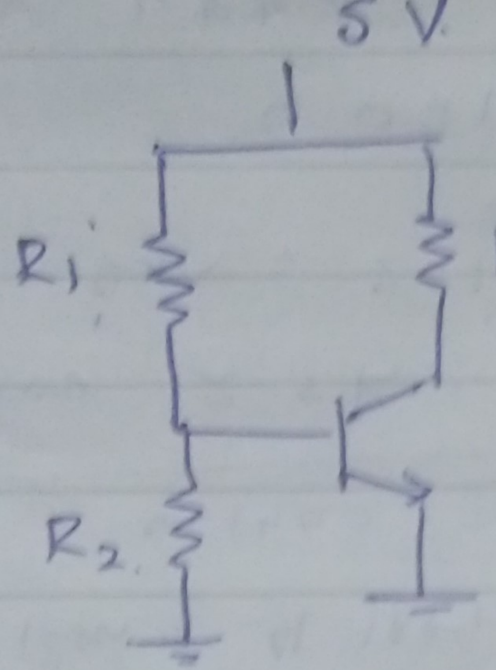
$$\therefore I_C = \beta \frac{V_x - V_{BE}}{R_B} = 100 \frac{1.232 - V_{BE}}{54.4k}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) = 0.026 \ln\left(\frac{I_C}{10^{-17}}\right)$$

$$V_{CE} = 3.85 - (3k)\, I_C$$

V_{BE} (V)	I_C (A)	V_{CE} (V)
0.7	977.94 µ	
0.838	724.26 µ	
$\boxed{0.83}$	$\boxed{738.97\,\mu}$	~~0.155~~ 1.633

Q.



Given $I_s = 5 \times 10^{-15}$ A

$\beta = 100$

$V_{th} = 26$ mV

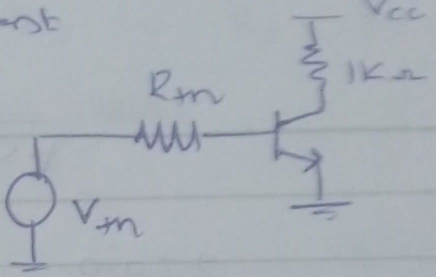
→ Iterate V_{BE} for stable value starting 0.7V

Find the changes in bias point when resistance variation of R_2 becomes $1.2 R_2$

Take ~~$R_1 = 6.38$ kΩ, $R_2 = 1.2$ kΩ~~, $R_C = 1$ kΩ

$R_1 = 13.944$ kΩ, $R_2 = 2.4$ k

sol: Draw thevenin's equivalent



$$V_{th} = \frac{V_{cc} \cdot R_2}{R_1 + R_2}$$

$$= \cancel{\frac{5 \times 8\ 1.2}{1.2 + 8.38} = 0.626}$$

$$= \frac{5 \times 2.5}{2.5 + 13.944} = 0.760\,V.$$

$$R_{th} = R_1 \| R_2 = \underline{\underline{2.12\,k\Omega}}.$$

Now find / ~~st~~ check for stable V_{BE}, I_C points assuming active mode of operation,

we know,

$$V_{th} = I_B R_{th} + V_{BE}. \quad \text{—(a)}$$

Also,

$$I_B \times \beta = I_C$$

$$I_C = I_S \cdot e^{(V_{BE}/V_T)}$$

for, $V_{BE} = 0.7V$, $I_C = 2.463\,mA$. —(1)

here $I_B = I_C/\beta = 24.6\,\mu A$.

Use it in (a),

$$V_{BE} = V_{th} - I_B R_{th} = 0.76 - 24.6\mu \times 2.12$$

$$= \underline{\underline{0.707\,V}}$$

$$I_C = 5 \times 10^{-15} \times e^{0.707/0.026}$$

$$= 3.22\,mA$$

V_{BE} on further iteration can be seen to be stable.

Thus the bias points I_C, V_{CE} calculation,

$I_C = 3.22\,mA$,

$V_{CE} = V_{CC} - I_C R_C = 5 - 3.22\,mA \times 1K$

$= 1.78\,V$

$2.6\,K\Omega$

$= 0.707V.$

changes R_2 to $1.015R_2$ (1.5%) $= 2.53275k\Omega$

$I_C = I_S e^{V_{BE}/V_T} = 2.46mA$

$I_B = 24.6\mu A$ (using $V_{BE} = 0.7V$)

Here $R_1 = 13.944k\Omega$ $\Rightarrow$ $R_{th} = 2.146k\Omega.$

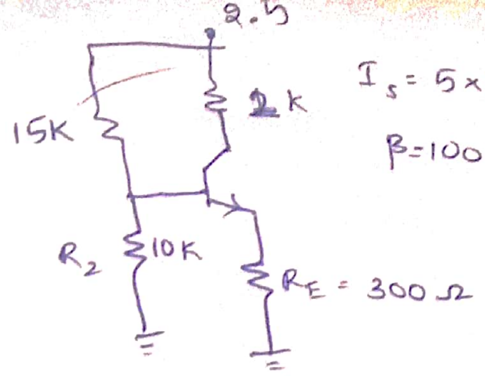
$V_{th} = 0.7\cancel{4}V.$

$\therefore V_{BE} = 0.717V.$

$I_C = 4.73mA. \Rightarrow V_{CE} = V_{CC} - I_C R_C$

$= 0.27V.$

$V_{TH} = 2.5 \times \frac{10}{25} = 1\,V.$

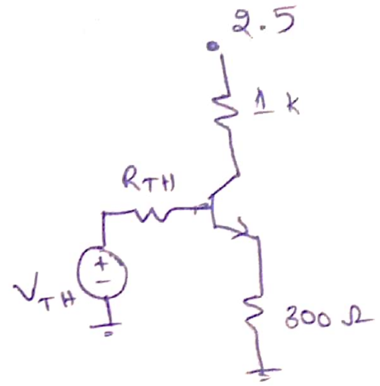


$I_s = 5\times10^{-17}\,A$

$\beta = 100$

$R_{TH} = 6\,k\Omega$

$$I_c = \beta \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)R_E}$$



V_{BE} (V)	I_c (mA)
0.8	0.55
0.78	0.606
$\boxed{0.783}$	$\boxed{0.59}$

$\boxed{I_c = 0.59\ mA}$, $V_c = 2.5 - (0.59\times 2)$
$\boxed{V_c = 1.32\,V}$, $\boxed{I_c R_E = 0.59 \times 300 = 177m}$

Cas (i) change supply voltage by +5% $= 2.5 + (2.5 \times 0.05)$
$= 2.625\,V.$

$\therefore V_{TH} = 2.625 \times \frac{10}{25} = 1.05\,V.$

V_x changed by 50 mV.,

V_{BE} (V)	I_c (mA)
0.8	0.68
0.788	0.72
0.787	0.72.

$\Rightarrow \boxed{I_c = 0.72\ mA}$

$\therefore V_c = 2.5 - (0.72\times2) \Rightarrow \boxed{V_c = 1.06\,V}$

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(ii) Change V_{cc} by -5%

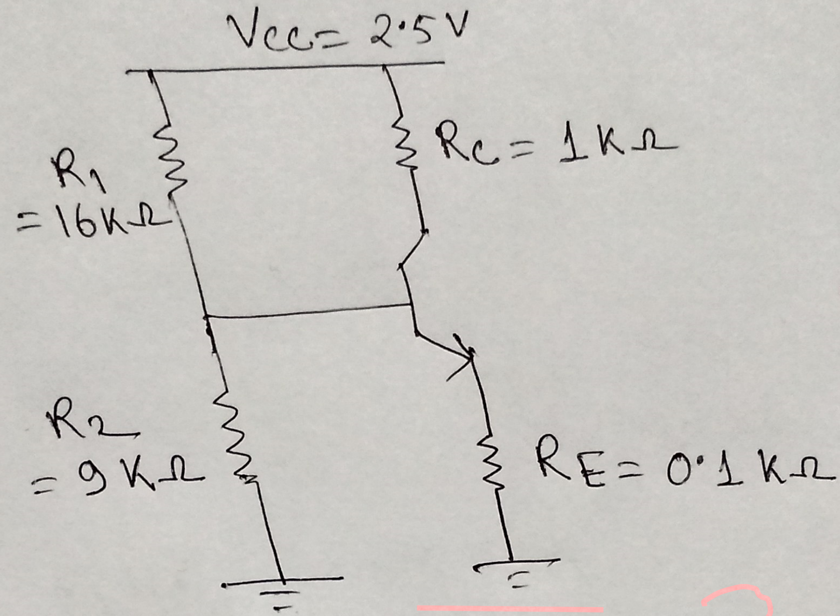
$V_{cc} = 2.5 - (2.5 \times 0.05) = 2.375$

$V_{TH} = 950$ mV.

V_{BE}	I_c
0.8	
0.777	0.47 mA.

$V_c = 2.5 - (0.47 \times 2) = 1.56$ V.

Q. Show that the following resistor divider circuit with emitter resistor is very robust and not very sensitive to resistor variation.



$\beta = 100$

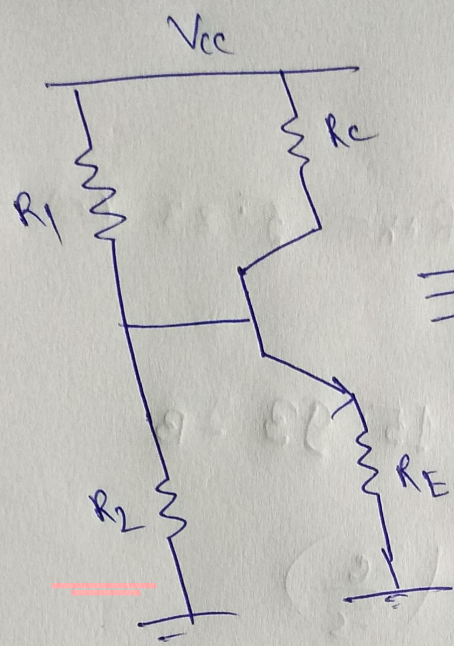
$I_S = 5 \times 10^{-17}\,A$

$V_T = 26\,mV$

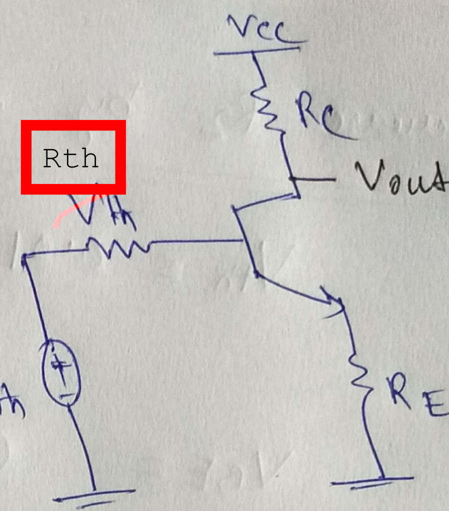
(i) Find V_{BE} and I_C (upto 2 iterations)

(ii) Increase R_2 by 2% and repeat (i).

(iii) Find the percentage increase or decrease in V_{BE}.



$\equiv$



$$V_{th} = I_B R_{th} + V_{BE} + (\beta+1) R_E I_B \quad \text{—— (1)}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) \quad \text{—— (2)}$$

$V_{th} = 0.9V$, $R_{th} = 5.76\ K\Omega$

$$V_{BE} = 0.9 - 15.86 I_B$$

assume $V_{BE} = 0.8$

V_{BE}	I_C
0.8 V	0.635 mA
0.785 V	0.73 mA
0.788 V	0.71 mA

$V_{out} = 1.79V$

Increase R_2 by 2%

$V_{th} = 0.91$ V $\quad R_{th} = 5.83$ kΩ

$V_{BE} = 0.91 - 15.93\, I_B$

$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$

assume $V_{BE} = 0.8$

V_{BE}	I_C
0.8 V	0.691 mA
0.787	0.772 mA
0.789	0.76 mA

$V_{out} = 1.74$ V